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PHYSICAL CHEMISTRY.—*The nature of the forces between atoms in solids.*[1] RALPH W. G. WYCKOFF, Geophysical Laboratory, Carnegie Institution of Washington.

The study of the arrangement of the atoms within a crystalline body and especially of variations in these arrangements with changes in the physical conditions of the solid, such as temperature and pressure, when taken in connection with the knowledge which has been accumulating concerning the nature of the atom, should give considerable information concerning the kinds of forces operating between atoms and between molecules. With this in mind the determination of the structures of a number of typical compounds was undertaken by the author about two years ago in the chemical laboratory of Cornell University.

It seems possible to arrange all crystalline solids in a number of groups according to the nature of the forces between their atoms. The general outline of such a classification is presented in this discussion. Because of the numerous speculations which have been introduced into recent discussions of the structure of the atom, it has seemed advisable to present the point of view which has served as a basis for this classification. The first part of this paper is given up to such a presentation.

J. J. Thomson,[2] G. N. Lewis,[3] and W. Kossel[4] have applied the present knowledge of the structure of the atom to a consideration of the nature of the forces of chemical combination. In developing the following discussion extensive use was made of the first

[1] This paper was written in February, 1919, but was still in manuscript when Langmuir's paper on a similar subject appeared (June, 1919).

[2] J. J. THOMSON, *The forces between atoms and chemical affinity.* Phil. Mag. (6) 27: 757–789. 1914.

[3] G. N. LEWIS, *The atom and the molecule.* Journ. Amer. Chem. Soc. 38: 762–785. 1916.

[4] W. KOSSEL, *Ueber Molekülbildung als Frage des Atombaus.* Ann. d. Physik (4) 49: 229–362. 1916.

of these papers. Recently I. Langmuir[5] has extended the theory of G. N. Lewis and has also tried to obtain from purely chemical considerations information about the more intimate structure of the atom. A. L. Parson[6] has applied his "magneton" theory of the atom to an explanation of chemical forces.

THE STRUCTURE OF THE ATOM

The "nucleus atom."—An accurate relation has been shown to exist between the wave lengths of the X-rays characteristic of the various elements and their order numbers in the periodic table.[7] This relation was discovered after the importance of this order number, known as the "atomic number," had already been urged.[8] Its bearing on the structure of the atom will be seen from the following facts.

If alpha particles are shot at a substance, a certain number of them will suffer a large change in direction. The "scattering" (change in direction) actually observed in the case of the various elements is that which would be expected if the atom possessed at its center a minute positively charged nucleus.[9] Experiments indicate that this charge has a magnitude Ne, where e is the charge on the electron and N is the atomic number.[10] Further, a study of the disintegration products of uranium and thorium shows clearly the variation of the chemical properties with variations in the nuclear charge.[11] These facts

[5] I. LANGMUIR, *The arrangement of electrons in atoms and molecules.* Journ. Amer. Chem. Soc. **41**: 868–934. 1919.

[6] A. L. PARSON, *A magneton theory of the structure of the atom.* Smithsonian Misc. Coll. **65**: No. 11 (Publication No. 2371). 1915.

[7] H. G. J. MOSELEY, Phil. Mag. (6) **27**: 703–713. 1914. If N is the order number of the elements, beginning with hydrogen as one, helium as two, lithium as three, etc.; ν the frequency of the corresponding lines in the X-ray spectra; A a constant which is the same for all elements; and b a similar constant having a value less than unity, then

$$\nu = A(N-b)^2.$$

[8] A. VAN DEN BROEK, Physik. Zeits. **14**: 32–41. 1913.

[9] E. RUTHERFORD, Phil. Mag. (6) **21**: 669–688. 1911; etc.

[10] H. GEIGER, Proc. Roy. Soc. A. **83**: 492. 1910.

[11] F. SODDY. *The chemistry of the radio-elements.* II. *The radio-elements and the periodic law*, p. 2. 1914. The loss of an alpha particle (doubly positive helium-atom) decreases the nuclear charge by two units producing an element placed two positions to the left in the periodic table. The loss of a beta particle (an electron) produces a shift of one unit in the opposite direction.

are most simply explained by considering the atom to be possessed of a very small nucleus carrying a positive charge equal to its atomic number. That the electron is a constituent of all matter can no longer be doubted. Then, since the atom as a whole is electrically neutral, enough electrons to neutralize the nuclear charge must be arranged about the central nucleus.[9] Thus the hydrogen atom is a small positive nucleus bearing a single positive charge and accompanied by a single electron; the helium atom is a doubly charged nucleus accompanied by two electrons; and so forth.

Loosely-bound electrons.—Some of the electrons in an atom may be expected to be more tightly bound than others. Close to the positively charged nucleus the electrical forces (and presumably also the magnetic forces) should be much stronger than farther away from the nucleus. Consequently those electrons which are close to the center of the atom will be held with greater force than the more distant electrons.

There are numerous indications[12] that the atoms do contain a small number of more or less weakly bound electrons. The application of the electron theory to the dispersion of radiation indicates the existence of such electrons. By using the relations which have been developed for the theory of dispersion it is possible to calculate roughly the number of dispersing systems in each molecule. If such a calculation is carried out for quartz, for instance, it is found that each molecule possesses three to four, probably four, "dispersion electrons." These calculations must be inexact, however, because the proper application of the expressions used requires a knowledge of all the vibrating systems in the molecule. Experimental difficulties, especially in the extreme ultra-violet, make this impossible.

Studies upon the absorption of light and the optical properties of metals furnish similar results. Metallic conduction is assumed to be due to electrons which possess a certain amount of freedom of movement. Then there are those electrons which, as is well known, can be liberated by light and heat; these also

[12] CAMPBELL. *Modern electrical theory.*

must be rather weakly bound. The positive rays are atoms which have lost a few electrons. Perhaps the strongest evidence, at any rate from the point of view of the chemist, that atoms possess a small number of loosely held electrons is furnished by the phenomenon of electrolytic dissociation. Since the magnitude of the electrical charges concerned is the same as that of the charge on the electron, the conclusion can hardly be avoided that a few electrons are involved. It is the natural thing to identify them with the "dispersion electrons" already mentioned. These outside rather weakly bound electrons are the ones involved in chemical changes.

Arrangement of electrons.—No real information is available concerning the exact arrangement of the electrons in an atom. These electrons must either be in motion about the nucleus (the revolving-electron type) or else they must be held in equilibrium positions about the center (the stationary-electron type). There are serious difficulties in the way of either arrangement.[13] Since the loosely bound electrons are the only ones involved in chemical reactions, the exact arrangement of the inner electrons is a matter of secondary importance to the chemist, at least for the present.[14]

From the standpoint of the chemist the stationary-electron atom seems simpler because its qualitative application is easier. This application can be made with either type of atom, however, and in the present state of our knowledge one is quite justified in imagining and using *for chemical purposes* whichever type of

[13] It may be of interest to chemists to restate the most obvious of these objections. If the electrons are in revolution about the nucleus and if light is an electromagnetic phenomenon, as it is firmly believed to be, then a continuous radiation of energy from the atom as a result of this motion would be expected. In a comparatively short time the atom would "run down," disintegrate. This may or may not be a fallacious argument. On the other hand, in the case of the stationary-electron atom, unless a hitherto unknown force of repulsion is assumed, it is hard to see why the negatively charged electrons do not fall into the positively charged nucleus and become neutralized.

[14] Also since chemical changes affect only the outside electrons, it is quite clear that chemical facts can present only the most indirect information concerning the inside electrons of an atom.

atom model meets his fancy (always remembering that his particular type of atom is only a convenience).[15]

Arrangement of outside electrons.—Although we are unable at the present time to determine the general arrangement of the electrons within the atom, the facts of chemistry furnish consider-

[15] It has been found *convenient* to picture an atom, the inner electrons of which are in rapid revolution, the outer electrons of which might be held in positions of equilibrium between the atoms in a molecule.

Langmuir (see note 5, p. 566) has suggested an ingenious arrangement for the electrons in a stationary model. The examples of the application of his model, however, to chemical compounds are those which would be equally well satisfied by any type of atom of the kind described above. As already stated, chemical facts, simply because they involve only the outside electrons, cannot give direct information concerning the arrangement of the inner electrons. The stationary- and revolving-electron atoms might differ from one another in the nature of the electrical fields surrounding the atom. The electrical fields about the revolving-electron atom would be expected to be quite uniform while those about the other type might be clustered in patches. In the Stark atom (*Prinz. d. Atomdynamik*, III) the "positive electrification" was grouped in patches and electrons took up equilibrium positions about these patches. It is not evident whether a definite choice between the two atom types can ever be made upon these grounds.

Langmuir has urged that the existence of charcoals and similar porous substances having the form of solids of large *apparent* volume, where each atom of carbon (taking charcoal to be specific) is surrounded by fewer than four carbon atoms, is a proof that the electrons are stationary within the atom. This does not necessarily follow. In a structure of this sort the valence bonds which were linked up with other atoms in the formation of wood are, in the charcoal, partly or completely saturated by holding adsorbed gas (as will be seen later, adsorbed gas is probably held to charcoal and similar substances by *primary valence bonds*). As indicated by Bohr (Phil. Mag. (6) **26**: 857. 1916) and discussed by Kossel (*op. cit.*) the four outside electrons in a revolving-electron atom in the case of carbon would be expected to place themselves, if possible, at the corners of a tetrahedron. As a consequence of these facts the large apparent volume of charcoal is not a proof of the inherently *directed* nature of the valence bonds of carbon. Many sulfides of large apparent volume are known which, when heated to a certain temperature, will suffer a rather sudden change in shape (and apparent volume), *i. e.*, they crumble. This quite possibly is due to the loss of adsorbed gas.

These objections are urged, not as proofs that the electrons are not stationary, but simply as showing that the evidence in favor of their stationary nature is not conclusive. The experiments of Hull (cited by Langmuir, *op. cit.* p. 869) are inconclusive. As S. Nishikawa has pointed out, the effects which led Hull to believe that electrons occupy definite positions in the crystal lattice are in some cases similar to those effects which would be expected to result from the thermal agitation of the atoms in the crystal. The best way to determine whether or not the effect is real would be to make the X-ray studies at a point where the specific heat is very small. The author hopes to make such a study in the near future.

able information concerning the outermost ones. As we pass along the periodic table horizontally from left to right, each atom differs from the one preceding it in carrying a nuclear charge greater by one and hence in possessing one more electron.[10] It is seen that with simple atoms (short series of the periodic table) the general characteristics of an atom repeat themselves after the addition of eight electrons: lithium and sodium are similar. With the long periods eighteen electrons (thirty-two in the last complete series) must be added before there is a complete repetition of properties. Three elements, those in the eighth group, exhibit a similar valence, so that there are really only twice eight kinds of valence (valence groups). There is, however, a partial repetition in the long periods after eight valence groups have been passed over. The sub-group elements show a valence similar to that of the primary elements: copper, silver and gold resemble the alkalies.

Radio-active phenomena and more especially the whole subject of electrochemistry emphasize the intimate connection between valence and the electron. The alkalies ionize losing one electron, the alkaline earths lose two; the elements of the oxygen group tend to acquire two, the halogens one; and so on. In 1904 Abegg[16] pointed out that the sum of what we choose to call the maximum positive and negative valences of an element is always equal to eight. Eight is the number involved in the recurrence of properties.

All of this seems to point clearly to some sort of repetition of the configuration of the outside electrons characteristic of the atom after the addition of eight outside electrons.[17] The repetition of properties is so striking that one is forced to the conclusion that when a certain definite number of electrons has been added to the outside of the atom, the force fields about the atom, except those resulting from the unneutralized charges upon the nucleus, become practically negligible. If hydrogen is the simplest element, this definite number of electrons in the case of the very simple elements (first short period of the table) is two. For the other simple elements it is eight. The heavier

[16] R. Abegg. Zeits. anorg. Chem. 39: 330. 1904.

[17] See references 2, 3, and 6, on page 565.

elements require twice eight additions to "close" the atomic fields effectively. Then an atom of an alkali metal has one outside electron, an alkaline earth two, and so on until we reach the halogen with seven outside electrons and the next inert gas with eight outside electrons, starting a new group.[18]

Tendency to form clusters of eight.—The fact that oxygen with six outside electrons and chlorine with seven are negatively bi- and mono-valent, respectively, points to the *existence of a tendency to form clusters of eight electrons.*[19] In other words, in

[18] The simple elements would probably be represented as follows (if hydrogen is the simplest element and helium comes next):

Element	*Nuclear Charge*	*Electron Arrangement*
Hydrogen	1 positive	1 electron
Helium	2 positive	2 electrons forming a "closed cluster" of two
Lithium	3 positive	3 electrons: inside cluster of two, one outside electron
Glucinum	4 positive	4 electrons: inside cluster of two, two outside electrons
Boron	5 positive	5 electrons: inside cluster of two, three outside electrons
* * *	* * * * *	* * * * * * * * * * * * *
Fluorine	9 positive	9 electrons: inside cluster of two, seven outside electrons
Neon	10 positive	10 electrons: inside cluster of two, "closed cluster" of eight
Sodium	11 positive	11 electrons: inside cluster of two, inside cluster of eight one outside electron
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Recently DEBYE (Physik. Zeits. **18**: 276. 1917), VEGARD (Ber. deutsch. phys. Ges. **19**: 328. 1917), and KROO (Physik. Zeits. **19**: 297. 1918) have tried to explain the K-series lines in the X-ray spectra of elements as due to an inside ring of *three* or *four* electrons. If this innermost ring preserves its character when we pass to the more complex atom, and if there are not one or two very light elements, as yet undiscovered, it is highly probable that this inside ring contains *two* electrons.

[19] A. L. PARSON, op. cit.

addition to the force holding the normal number of electrons to the nucleus, there is a force which causes the atoms to tend to add electrons beyond the number equal to the positive charge on the nucleus.

The force responsible for this tendency to form eights may be mainly an electrostatic attraction between positive and negative charges. This has been mentioned by Langmuir:[20] "According to ordinary potential theory, electrons uniformly distributed throughout a spherical shell should exert no forces on electrons inside the shell, but should repel those outside the shell as though the electrons in the shell were concentrated at the center. On the other hand, an electron in the spherical shell itself is repelled by the others in the shell as if one-half of the other electrons were removed altogether, while the second half were concentrated at the center. Thus, let us consider a carbon atom ($N = 6$) which has taken up 4 extra electrons and has completed its octet. An electron in the outside shell is thus attracted by the nucleus which has 6 positive charges, is repelled by the two electrons in the first shell as though they were concentrated at the center, and is repelled by the 8 electrons in the outside shell as if 4 of them were concentrated at the center. The repulsion of the electrons is thus only just able to neutralize the attraction by the nucleus, notwithstanding the fact that the whole atom has an excess of 4 negative charges." In the case of an oxygen atom ($N = 8$) which has acquired two electrons to complete its cluster of eight electrons, an electron in this outer cluster is attracted by the positive charge of eight units and is repelled by the equivalent of a negative charge of six units (by the two inner electrons and by the outer eight as if four were concentrated at the center). There is thus a strong extra attraction holding these additional electrons to the neutral oxygen atom. Fluorine would hold a single extra electron still more strongly.[21]

[20] Op. cit., p. 909.

[21] This discussion considered only the case where the electrons were distributed uniformly throughout a shell. A similar state of affairs will exist if the inside electrons are in revolution.

We can thus account for the existence of a tendency to add electrons beyond the number numerically equal to the charge on the nucleus but we are unable to state why electrons will add on to the atom to form clusters of eight rather than seven or nine or some other number[22] and why the formation of the cluster of eight results in such a great condensation of the fields of force about the atom. For our purposes the recognition of this tendency is all that is necessary.

Chemical valence.—Valence, then, *might* be defined simply as the tendency for the electrical (and probably also the magnetic)[6] fields to condense together to the greatest possible extent with the possession of an outside cluster of eight (also sometimes a cluster of two and sometimes a cluster of twice eight) electrons. The repetition of properties after the addition of eight electrons and the existence of a tendency to add electrons with the formation of clusters of eight were recognized by J. J. Thomson;[2] they underlie the application of the "magneton" atom of A. L. Parson[6] and the "cubical atom" of G. N. Lewis;[3] and they form the basis of what Langmuir[5] has chosen to call "the octet theory of valence," which is simply the application of this undeniable tendency to the representation of chemical compounds.[23]

Doublets.—Two electrical charges of opposite sign form a *doublet*, the moment of which with respect to an outside point (roughly, the effect of which upon an outside point) increases as the distance apart of the poles becomes greater.[24] Such doub-

[22] Langmuir's idea of cells suggests an explanation of this, but it must be borne in mind that his work only gives a possible geometrical arrangement of points of one kind about a point of a different kind and does not discuss how such a system could be physically stable. If the only forces of attraction and repulsion acting are those with which we are now familiar, such an atom model is unstable. As long as this theory is used simply as a convenient aid in picturing the atom it may prove useful to the chemist, but as yet no evidence has been presented to show that this model represents the actual arrangement of the electrons in the atom.

[23] As was earlier implied, these various discussions are not setting up new theories of valence but are indicating the explanation which the knowledge of the structure of the atom has to offer of the facts of valence as we have learned them.

[24] A doublet of this sort can be conveniently pictured. The fields of force between two electrical charges can be represented by lines (really tubes of force) passing from one to the other. The *number* of the lines serves as a measure of the intensity of the field. If the two charges are close together, the lines of force are for the

lets will exist within an atom possessing electrons and a positively charged nucleus.[25] The formation of the clusters of eight electrons so condenses together the lines of force about the atom that their moments with respect to other atoms are nearly negligible. Where the outside loosely bound electrons are concerned, the fields about the doublets become of the utmost importance in determining the chemical and physical properties of bodies.

Magnetic fields of the atom.—This discussion has taken no account of the magnetic fields about the atom. That atoms are possessed of fields of their own is shown by the effect of large outside fields upon the spectrum lines,—the Zeeman effect—and by various other lines of evidence.[26] It is probable that a detailed discussion of these magnetic effects would remove many of the difficulties arising from the application of such a theory as the present one. Certainly such a discussion must accompany any entirely general or quantitative theory. The "magneton" theory of A. L. Parson[6] is an attempt in this direction. Contradictions to some of the most commonly accepted ideas (such as the point-electron and the Rutherford type of atom) which Parson's theory presents make it simpler to neglect, at present, consideration of magnetic phenomena. It is probable that the magnetic forces influence in a marked degree the intensity of bonding between atoms but that their consideration will not introduce any new kinds of linkage.

Forces between atoms.—Conditions of equilibrium require the action of forces of attraction and repulsion. Uncertainties concerning the size of the atom make themselves felt in a consideration of the forces of *repulsion*. We find that the distance between the atoms in a solid[27] is of the order 10^{-8} cm. The actual

most part concentrated in the small space between the charges, so that the intensity of the field at any point (m) at a distance from both charges is slight. In other words, the moment of the doublet with respect to the point is small. If the separation of the charges is greater, the field will be more spread out, more lines of force will pass through m, and the moment of this new doublet with respect to m is much greater.

[25] J. J. THOMSON, op. cit.

[26] See W. J. HUMPHREYS. Science, N. S. 46: 273–279. 1917.

[27] W. H. BRAGG and W. L. BRAGG. *X-rays and crystal structure*, Chap. VII.

size of the atom may be very small compared with this distance. Atoms in a solid would then be held apart by some repulsive force, the intensity of which must decrease rapidly from the origin. Concerning its possible nature we have no inkling. Presumably the heat vibrations would aid this force. But the diameter of the atom, meaning the diameter of the outermost ring of electrons, may be comparable with the distance apart of the atoms. The tightly drawn-in fields about the closed groups of electrons make the atom, except for a few valency electrons, behave like an elastic solid, so that two atoms can interpenetrate only to an extent involving these outside electrons. This effect, together with the thermal agitation, is quite sufficient to explain the ordinary phenomena observed. The assumption of a further repulsive force, essential to the other theory, does not seem necessary. The view that the atoms are held apart simply as the result of their own impenetrability and their thermal vibration will therefore be used.

The influences of which we are aware that affect the combination of atoms one with another are then:

1. The electrostatic *attraction* between positively charged nuclei and negatively charged electrons.

2. The large condensation and drawing in of the fields of force which accompany the formation of certain clusters of electrons (two, eight or twice eight). The result of (1) and (2) is an apparent *tendency to* FORM *clusters of electrons*.

3. The thermal agitation of the atoms (and probably in certain cases groups of atoms acting together) which acts as a force of repulsion.

4. The magnetic fields (our ideas of which are at present of an indefinite nature).

Exterior structure of the elements.—An alkali metal results when the total number of electrons needed to form the "closed clusters," including the outermost "closed cluster," is 1 less than that required to neutralize the nuclear charge, *i. e.*, there is one outside or "left-over" electron. The closed cluster in the case of lithium contains fewer electrons than eight, presumably two. So few electrons can hardly be expected to draw

in very completely the fields about the atom. With sodium, possessing a single cluster of eight electrons, the fields are more condensed. Where clusters of twice-eight electrons are effective (potassium, rubidium, caesium) the outside fields become of little importance. This suggests an explanation for the marked difference in properties exhibited by the transition elements of a group. As the atom gets larger the detachable electrons become farther removed from the nucleus and consequently less tightly bound. Elements of the sub-group have a single cluster of eight so that, although they resemble the alkalies in having a single outside electron, the forces about the atom which tend to enmesh and hold the electron are very much greater.

The atoms of the other groups will be similarly constituted. Those of the second group possess two outside electrons, the third three, and so on, up through the eighth group.

For the eighth group the theory is not so simple. In this group there is a single cluster of eight electrons and no outside electrons. The atom is quite complex, however, and a single cluster of eight electrons is unable to close the fields completely. As a result the atom possesses considerable reactivity. The facts of chemistry show that, perhaps on account of the vigor of these forces, two and sometimes three of these electrons can be detached. The existence of three similar elements in this group is *conveniently* explained by the assumption that at this point, when the two additional electrons are added, rearrangements of the internal rings are more stable than the addition of an outside electron.[28]

The character of the rare-earth elements could be explained by an assumption like the last one, namely, that when this point in the periodic series is reached, the stable arrangements, for a number of successive increases in the nuclear charge, result

[28] The system is seen to be tending towards a more stable condition with each readjustment. The outside fields become more and more drawn in and the electrons become less loosely bound. This is shown by the transition in properties from iron, Fe'' (less stable) and Fe''' (more stable), through cobalt, Co''' (less stable) and Co'' (more stable), to nickel, Ni'' only.

The assumption made by Langmuir that ten electrons are necessary to form the first half of the larger closed groups is about as satisfactory. In the absence of any real information upon the subject either can be used.

from a rearrangement of the electrons among the interior rings rather than from the addition of electrons to the atom surface. But this assumption, in common with every other yet made regarding the arrangement of the electrons in the eighth-group and rare-earth metals, is not very satisfactory as a description of the real arrangement of the electrons in these atoms.

The behavior of hydrogen is interesting. In water solution of many of its compounds it behaves as if strongly "electropositive." This would indicate that it lost an electron with great readiness. But in most of its properties hydrogen acts like an element which holds on to electrons with great tenacity: its salts with weak anions are much less dissociated than the corresponding alkali salts; it occupies a position quite low in the electromotive series table; many of its compounds are volatile, and its diatomic molecule is very stable. This apparently anomalous behavior of many hydrogen compounds follows directly from the structure of its atom. As long as hydrogen possesses a single electron, it holds on to it energetically and tends to acquire another to close its fields; if the electron is removed, the only force exerted by the atom is due to the attraction of its single positive charge.

THE STRUCTURE OF CHEMICAL COMPOUNDS, PARTICULARLY SOLIDS

Polar and non-polar compounds.—All chemical compounds may be considered as included within the following extremes, compounds the constituent atoms of which are electrically

1. Charged,
2. Neutral.

If the atoms are charged, the compound is "polar;" if neutral, it is what is now called a "non-polar" compound.[29]

In a polar compound the tendency of the electronegative atom to complete a cluster of eight is so much greater than the attraction of the positive nucleus of the electropositive atom for the outside electrons that the electronegative atom is able to remove them completely.

[29] W. C. Bray and G. E. K. Branch. Journ. Amer. Chem. Soc. 35: 1440–1447. 1913.

A non-polar compound is held together by the entangling of the fields of force about the constituent atoms. No electron transfer occurs. Each atom may be considered as drawing electrons from another in the endeavor to complete a stable group. In such a union as this, one unit of valence is equivalent to two "free" chemical "links," that is, one chemical "bond" in the compound.[30] Such a non-polar compound would of course have to be formed between atoms which held their electrons with about equal intensity.

All gradations between these two extremes probably occur where the bonding electrons, taking up positions between the two atoms, may be thought of as belonging to both. Most compounds, especially in the vapor state, must lie in this intermediate class. A given compound is not necessarily polar or non-polar in all its states of aggregation; it may shift from one class toward the other. In the solid and liquid states the close proximity of other atoms has a strong influence upon the properties of a molecule.[31]

States of aggregation.—When the total attractive forces between the units (molecules) of a substance is less than the repellent forces of thermal agitation, the molecules will part from one another and the substance is said to be in the gaseous state. The less the attractive force compared with the thermal agitation, the more "perfect" will be the gas. A liquid results when these residual fields (stray doublet fields) just exceed the effects of the heat vibrations. When the fields become relatively very large and the atoms are able to take up definite positions, the substance solidifies. Of greatest importance in causing the

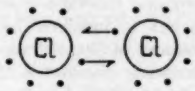
[30] J. J. THOMSON (op. cit.) has indicated this fact. Using the idea of Faraday tubes of force, as he does, we would say that unless a cluster of eight is formed the valency electron, to be fixed in position, requires that it shall have tubes of force running to two atoms, one other besides the one to which it belongs. This will be quite evident when typical cases, chlorine and methane, have been considered.

[31] When molecules approach one another, there will be an interlocking of their stray fields. A certain weakening of the fields of the molecule itself will result. With doublets of large moment, where the separation of the charges is great, the fields will be spread out and the interlocking may be of marked effect upon the molecule.

individual molecules to stick together are the electrical doublets. The greater their moments the more important will be their effect upon neighboring atoms. Consequently polar compounds tend to be strongly aggregated. Nearly all such compounds are solids at ordinary temperatures. The lower the temperature the less the repulsion and the more the particles cling together. At a sufficiently low temperature, the absolute zero, a substance possessing even the smallest outside fields would be a solid simply because the heat motion of the atoms, and consequently their repulsion, vanishes.

The effect of the intensity of combination is complicated. If the bonding forces in the gas molecule of a particular compound are so large and the residual forces so small that the molecule remains a definite entity in the liquid and solid states, it will in general be true that the greater the bonding forces, the more bound-in will be the fields and the less will be the degree of condensation. If, on the other hand, we have a compound in which the molecule as we ordinarily understand it disappears in the condensed states, and the entire portion under consideration appears as one large molecule, it would seem to be true that the more intense the bonding the *more* condensed is the system.

Formation of molecules in non-polar substances.—At room temperature the molecule of chlorine is diatomic. The chlorine atom possesses seven outside electrons and the tendency to pick up one more and close the cluster is considerably greater than the repellent effect of the heat vibrations. The molecule can be represented somewhat as follows:[32]



[32] There is a certain interest and importance attached to the representation of compounds by the use of graphical formulas. The conventions in common use do not indicate the nature of the forces between atoms. The representation, by G. N. Lewis (op. cit.), of the *distribution* of the outside electrons between the atoms in chemical compounds is a distinct advance in the writing of graphical formulas. But his method has certain disadvantages. It is often tedious and, moreover, unless considerable space is devoted to the formula, it does not show the *positions*

each atom striving to claim an electron from the other. This arrangement will quite completely close the fields about the molecule as a whole and the diatomic chlorine molecule (Cl_2) will possess relatively little residual affinity. As the temperature is raised the increased energy results (1) in a larger vibration of the atoms within the molecule, and (2) more especially in the increased violence of the motion of the molecule as a whole. Thus there will come a time when some of the molecules will be traveling with so great a speed that the violence of their collisions will be sufficient to cause the splitting of the molecule. At this point we begin to have monatomic chlorine. The number of simpler molecules increases faster than the increase in temperature at a rate depending upon the importance of factor (1). The amplitudes of the atomic vibrations depend in an inverse ratio upon their weights and the intensity of the bonding. It is to be expected that the dissociation of a weak compound under the influence of heat will proceed at a faster rate than when the union is strong. Increase in temperature raises the reactivity because with larger intra-molecular vibrations the fields of force

of the electrons. The pictures used by Lewis and adopted by Langmuir give, as representations of space models, a truer idea of the actual state of affairs within compounds, but, by reason of their complexity, are not in most cases sufficiently useful to be practicable.

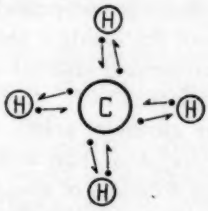
It has been found useful to designate the mode of combination, where this added information is of value, by the following modifications of the ordinary chemical "bonds." The passage of an electron from one atom to another is shown by a full-pointed arrow. Caesium chloride, in which the chlorine atom has captured the outside electron of the caesium atom, is $Cs \longrightarrow Cl$. The holding of an electron in an equilibrium position between two atoms, as in bromine vapor where each bromine atom of the bromine molecule is striving to acquire one electron from the other bromine atom, can be indicated by a half-pointed arrow pointing in the *direction* of the displacement of the electron (as, $Br \rightleftharpoons Br$). If it is of advantage to know the approximate *amount* of this displacement, which serves of course as a measure of the doublet fields set up, this can be done by cutting the arrow with a dash at the approximate position of the electron. Thus $A \longrightarrow B$ would mean that B was drawing one of A's electrons with a pull sufficient to displace it to a position half the way towards B.

The diagrams given in the text are a combination of this method of representation with the idea of showing the distribution of all the outside electrons.

are gradually becoming more opened up and hence more readily broken up by other atoms.

As the temperature is lowered, if the pressure is made sufficiently high, that is, if as many molecules are furnished within a definite space as could possibly be needed, the tendency of the molecules to stick together will approach in value the tearing-apart tendency of the heat motion. The critical temperature is the point where these opposing tendencies are equal. At no higher temperature can the gas be liquefied; at all lower temperatures the substance can be condensed. As the temperature of the liquid is lowered the motion of the molecule becomes less and less till at a certain point the residual forces of attraction (stray fields) become able to hold the molecules in definite positions. This happens at the melting point. According to this view solid chlorine consists of molecules held together by stray fields. Valency forces are involved in holding the atoms together in the molecule.[33]

Methane is a substance of the same type. A molecule of methane may be represented thus:



It has a normal dielectric constant and presumably does not possess any doublets of large moment.[2] This indicates that the tendencies of either carbon or hydrogen to acquire electrons

[33] It is possible that with the close proximity of other atoms, both the ingoing and the outgoing unions will not remain directed towards the same atom. In that case each atom would be linked by primary valence with two atoms, each of which would be linked with other atoms and so on throughout the mass. With this state of affairs the molecule as ordinarily understood would lose its identity. The smallest unit, aside from the atoms themselves, becomes the entire mass. This is a possible structure for solid chlorine. There is at present no evidence in its favor. If this second view is correct the vapor subliming from the solid ought possibly to contain an appreciable number of monatomic molecules.

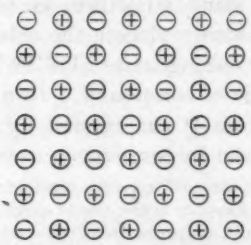
to complete the clusters are not nearly so great as the tenacity with which hydrogen and carbon retain electrons. The electrons consequently are not appreciably displaced from their equilibrium positions. The stray fields are relatively small and the gas liquefies at a rather low temperature. The chemical molecules preserve their identity in the liquid and solid states, being held to one another by the relatively slight secondary attraction.

Carbon compounds in general are characterized by great stability, due to the intensity with which carbon clings to its electrons, and by the smallness of the residual attractions possessed by the molecules of such compounds. In passing horizontally along the periodic table, when carbon is reached the tendency to add electrons with the formation of a stable cluster is not as yet so great that carbon is able to capture electrons from other atoms, and consequently there are no doublets of large moment. The properties of organic compounds in general force the conclusion that in the solid and liquid states the chemical molecule remains just as definite an entity as in the vapor. Practically all but the simplest compounds are solids or liquids, in spite of the weakness of the residual forces, because such large molecules require a considerable amount of heat energy to produce even a small displacement.[34] Certain kinds of organic compounds, such as the alcohols, acids, and nitro- and nitrile-compounds, are more associated than would be expected. This is due to their possessing doublets of considerable moment.[2]

Formation of molecules in polar substances.—With compounds of the polar type the mechanism is quite different. The tendency of chlorine to acquire one electron is so great and the holding power of sodium for the one outside electron is so weak that in a molecule of sodium chloride vapor the electron may be considered to have gone over most of the way to the chlorine. A molecule of sodium chloride vapor may be represented thus:

[34] Information from the specific heats and from the variations in the specific heat with temperature should be of interest in this connection.

A doublet of very large moment exists in this molecule and sodium chloride vapor would be expected only at an elevated temperature. In the solid and liquid states each sodium atom (except those upon the surface), positively charged by the loss of an electron, is surrounded by several chlorine atoms, all negatively charged.[35] These other chlorine ions, each possessing a pull upon the sodium ion, will more or less completely tear apart the fields which in the gaseous state bind the sodium atom to one particular chlorine atom. Sodium chloride becomes a body of ions held together mainly by the electrostatic forces of attraction between opposite charges. A cross-section of a crystal of sodium chloride would appear thus:[36]



The gaseous molecule disappears quite completely. A study of the effect of a sodium chloride crystal upon X-rays leads to belief in such a structure.[37]

Concerning the liquid state of sodium chloride we know practically nothing. It would seem most reasonable to assume a structure similar to that possessed by the solid, with the added fact of mobility; that is, an agglomeration of an equal number of positive and negative ions. When such a solid sublimes, ions should appear in the space above.[38] In general all crystals made up of strongly electropositive and electronegative elements are

[35] Sodium chloride possesses absorption bands in the extreme infra-red which are produced by *charged* particles of *atomic* mass.

[36] This structure for sodium chloride and similar crystals has been suggested by STARK, *Prins. d. Atomdynamik*, III. p. 193.

[37] W. H. and W. L. BRAGG. *X-rays and crystal structure.*

[38] The chemical molecule is in certain cases a natural consequence of the belief in atoms. It is not, however, in all cases a necessary consequence. If we are to imagine two or three atoms, each with a certain tendency to react, coming together,

of this type. Sodium nitrate and calcium carbonate[37] are examples. In these cases the nitrate and carbonate ions act as single units. Three factors are of importance in determining the crystal form of such substances:

1. The stable arrangement of points in space which correspond in charge and number with the ions of the substance.

2. The number and arrangement of the atoms making up the ions.

3. The volumes of the ions.

The sodium chloride arrangement is the simplest possible for the grouping of an equal number of positive and negative particles of about equal volume. Sodium nitrate and calcium carbonate have the same structure as sodium chloride, the nitrate and carbonate ions replacing the chlorine ions.

Valency compounds.—Magnetite ($Fe''Fe'''_2O_4$) is an example of another general type of compound. In a crystal of magnetite each divalent iron atom is surrounded by four oxygen atoms, each trivalent iron atom by six oxygen atoms, and each oxygen

it is natural to suppose that they will combine together to form a definite whole—the molecule. This is what happens in the case of gases. The first actual evidence to show the existence of molecules came from the study of gases. This evidence is furnished by the Gay-Lussac Law of Volumes. The splendid success of the kinetic theory in describing the behavior of gases pointed in the same direction. When gas molecules had been shown to exist, a tendency to apply the idea of molecules to solids and liquids as well made its appearance. The extension of the gas laws to the case of dilute solutions showed that in this case the material of the dissolved substance is distributed throughout the solvent in a molecular condition, that is, as single atoms or as groups of a few atoms together. Only in these two cases, gases and dilute solutions, have we sure evidence of the existence of molecules. Certain observations upon solutions of solids in solids would seem to indicate for them a structure similar to that possessed by liquid solutions. The abnormal behavior of some pure liquids finds its simplest explanation in the assumption of a molecular structure. Because of this certainty of the existence of the molecule in gases and in solutions, and because with organic solids and liquids it is quite impossible to imagine any other than a molecular composition, chemists in general seem to have felt justified in concluding that all matter is molecular in structure. It is important to note that this conclusion is only an inference, in no way justified by experimental evidence, and that the recent evidence which has appeared, tending to show that certain kinds of solids and liquids are *not* made up in such a way that each piece consists of a large number of chemical molecules, is merely destroying some generally-held opinions and is not in any way contradictory to our previously acquired knowledge.

atom by four iron atoms.[89] The diamond, carborundum, certain oxides and sulfides, and presumably nitrides and carbides, are compounds of this kind. The elements which go to make these substances are not strongly electropositive or electronegative, so that no actual electron transfer takes place. Completely closed groups are not formed and each valence unit corresponds to two bonds. The atoms in such a crystal are held together by valency forces. The chemical molecule does not appear; the entire crystal behaves as a single chemical individual.

It is improbable that liquids of this sort can exist. Certainly such compounds cannot be vaporized without undergoing profound changes. It is possible that at elevated temperatures the electronegative element may be able to relieve the other of electrons. Such a substance, when existing in the liquid state, would belong to the class previously described, the polar type of compounds.

Metals belong to the polar type. Just as the close proximity of other atoms in the case of sodium chloride is sufficient to break up the fields binding one particular sodium atom and one particular chlorine atom, so in the metallic state the presence of other atoms breaks up the fields holding certain electrons to the metal ion. A metal may be considered as a compound of metal ion and electrons entirely similar to a liquid of the polar type, which is a compound of metal ion and negative ion. The peculiar properties characteristic of metals are due to the fact that the electrons as a result of their minute size are readily able to pass between the atoms. This mobility makes the mechanism within the metal resemble that within a fused electrolyte. The atoms in intermetallic compounds, which presumably exist as such only in the solid state, are held together by the same forces that hold metal ions together in the pure metal. If a certain grouping of atoms offers an especially marked condensation and drawing-in of the fields of force, that grouping will appear as one of these compounds.

Classification of crystalline solids.—The crystalline state furnishes the greatest condensation of the fields about the indi-

[89] W. H. Bragg. Phil. Mag. (6) **30**: 305. 1915. S. Nishikawa. Proc. Tokyo Math. Phys. Soc. **8**: 199. 1915.

vidual particles (atoms or molecules, depending upon the type of solid).[40] Three limiting types of crystalline solids may be said to exist:

1. *Molecule-forming compounds.*—The atoms are held together in molecules by valency forces. The molecules, in turn, are held together in the solid by relatively weak stray fields. Compounds giving solids of this nature do not possess large doublets.

2. *Polar compounds.*—The atoms are held together by electrostatic attractions. The chemical molecule has disappeared.

3. *Valency compounds.*—The atoms are held together by valency forces. The molecule is the entire crystal.

Combinations of these classes and all transition stages between them are found. In sodium nitrate the nitrogen and oxygen atoms are held together by valency forces to form the nitrate ion. The combination between the sodium and the nitrate group is polar. The silver and mercury (mercurous and mercuric) halides are probably midway between (1) and (2). In a crystal of silver iodide, because of the vigor with which silver clings to the one electron, the electron may be considered as placed part way between the silver and the iodine atoms. The *molecules* of silver iodide are held together partly by the stray fields and partly by the fields of the doublet of relatively small moment.

A brief discussion of certain phenomena which illustrate the application of this point of view will now be given. Some of these subjects have been considered already from similar points of view.[41] They are given again either because they are especially helpful to an understanding of the previous discussion or because of their importance in the consideration of the structure of solids.

Dissociating Solvents.—The hydrides of the electronegative elements furnish the strongest dissociating solvents. Methane has been dealt with in detail. The fields of its molecule are quite

[40] If the substance is cooled very rapidly it may be impossible for the particles to arrange themselves in an orderly fashion. The solid is then amorphous.

[41] E. C. C. Baly. Journ. Amer. Chem. Soc. 37: 979–993. 1915; also papers in Trans. Chem. Soc. London. I. Langmuir. Journ. Amer. Chem. Soc. 38: 2221–2295. 1916; 39: 1848–1906. 1917; 40: 1361–1403. 1918. W. D. Harkins, E. C. H. Davies and G. L. Clark. Journ. Amer. Chem. Soc. 39: 541–596. 1917.

thoroughly saturated. With ammonia the tendency for nitrogen to acquire electrons is so much greater than the ability of the hydrogen to hold them that the electron of hydrogen is displaced quite a distance towards the nitrogen atom. Doublets of very considerable moment are thus set up within the ammonia molecule and are of large effect upon other atoms or molecules nearby. In water, doublets of still greater moment are to be distinguished on account of the more pronounced tendency of oxygen to acquire electrons. In hydrogen fluoride the single doublet is of even greater moment.

In the water molecule each of the two doublets is of slightly greater moment than each of the three in ammonia. However, the fields about the molecule of water are much more important than those about the ammonia molecule largely because of the comparative simplicity of the former. The hydrogen atoms in ammonia must lie in three different directions; the water molecule requires at most two directions, and probably both hydrogens would be in a line (the symmetrical arrangement). Consequently the turning of the water molecule in order that it may exert its maximum effect is much simpler a process than the corresponding process for ammonia.[2] Concerning the fields about hydrogen fluoride there is relatively little information. The molecule is not much simpler than the molecule of water; the single doublet does not possess a very much greater moment than either of the doublets of the water molecule.

The fields about the water molecule seem to be the strongest of those considered. In liquid water the combination between two molecules due to the interlocking of these doublet fields draws in the fields so that those about the "dihydrol" molecule are much lessened. The dihydrol is a fairly stable compound. Such a liquid, in which combination with itself is possible, is said to be "associated." The fields are intense enough and sufficiently localized to make possible combination between two, occasionally more, molecules but not strong enough to cause solidification. Organic acids associate by reason of the intensity of the combinations between the —COOH groups of different molecules, and alcohols because of the association of —OH groups.

Adsorption.[42]—There will be fields of force upon the surfaces of all solids and all liquids. The molecules of the gas surrounding the solid likewise possess stray fields of greater or less importance. One of two things will happen to those gas molecules which strike the surface of the solid (or liquid).

1. If the molecule is moving so fast that its energy exceeds that necessary to hold together the two fields, it will be reflected from the surface with a loss in energy depending upon the stray forces.

2. Otherwise it will condense and be held upon the surface. The molecule may by reason of collisions from other molecules acquire enough energy to enable it again to leave the surface. The average life and the number of atoms upon the surface at any one time will depend upon the balance set up between these opposing tendencies. As a result of the condensation (adsorption) a new surface, really one of the adsorbed substance, is produced.

From this point of view adsorption is seen to depend upon the following factors:

1. The adsorbed substance. The greater the outside fields of the molecules, the higher will be the adsorption.

2. The adsorbing substance. Solids of the valency and polar (electrolyte) types should have large surface fields and should adsorb strongly. Those solids, the particles of which are held together by stray fields only (the organic type), will adsorb to only a slight extent if at all.

Solubility.—Solubility results from the entangling of the fields of force of the solute and solvent. The process is influenced by:

1. The intensity of the residual forces of the solvent. When these forces are large, the degree of association of the liquid will furnish a rough measure of the forces. With weaker non-associating liquids the boiling point, combined with the weight of the molecule, gives the desired information.

2. The intensity of the residual forces of the solute. The various kinds and degrees of these have been discussed under a consideration of various typical solids.

[42] I. LANGMUIR. Phys. Rev. 8: 149–176. 1916; Journ. Amer. Chem. Soc. 40: 1361–1403. 1918.

It seems possible to state as a general rule that strong solvents (*i. e.*, those possessed of large external forces) dissolve strong solutes, while weak solvents dissolve weak solutes. Weak solutes are not usually markedly soluble in strong solvents nor is the reverse case true. Water dissolves electrolytes; carbon disulfide and benzene dissolve organic compounds; but electrolytes are not appreciably soluble in carbon disulfide or benzene, while water dissolves only those organic compounds which are possessed of large fields—the acids, alcohols, sugars and the like.

Solubility results, in fact, from a chemical reaction between solvent and solute. In order that marked solution can take place, it is necessary that the stray fields about the solvent and the dissolving substance shall each be strong enough to "open up" and make reactive the condensed systems of the other. A certain solubility can be considered to exist in all cases unless the temperature is carried too low. The ordinary tendency for the solute to "vaporize" into the liquid will be enhanced to an extent depending upon the added stray fields of the solvent.

The solubility of molecular compounds in non-associated liquids is perfectly straightforward. There will always be some solubility, increasing in amount as the solvent fields, which in such liquids are already pretty well opened up, become of increasing importance compared with those of the solute. In order that a substance may be strongly soluble in an associating liquid, it must possess fields great enough more or less to break up this association. Two types of solids have strong outside fields: valency compounds and electrolytes. The fields upon the surface of valency solids are due to the tendency of the surface atoms to complete their clusters of eight electrons. Except directly upon the surface, a valency compound is very thoroughly saturated. The surface atoms will be able to combine with the solvent molecules, but little action will result because of the much greater force within the solid material. Adsorption, rather than solution, results from this reaction. Electrolytes possess doublets of large moments which are able to open up to a large degree the fields of the solvent. The extent of the solution of an electrolyte depends upon

1. The degree of association of the solvent (which might be taken as a measure of the potential reactivity),

2. The moments of the doublets within the solid,

3. The stray fields within the solid.

In solids possessing multiply-charged ions the increase in the intensity of the binding fields would, where a condensing together of the fields is possible, be greater than the increase in the moments of the doublets. There would thus be a smaller tendency to dissolve. This tendency to condense together, which would ordinarily be found occurring with a double bonding, depends upon both the number and arrangement of the atoms within the solid. Calcium carbonate is only slightly soluble in water while sodium nitrate,[43] possessing the same structural arrangement, dissolves readily. If the ion possesses about it considerable fields, it may be able to form with the molecules of the solvent more or less short-lived compounds.

This point of view suggests for ionization a mechanism somewhat different from that usually accepted. A salt does not usually become ionized at the moment of solution; it is already ionized in the solid state. When a crystal of sodium chloride is added to water, ions, not molecules, are torn from the solid by the process of solution. These ions may, and will when there are enough of them present, combine temporarily to form sodium chloride molecules. The process of solution and ionization is not $\underset{\text{solid}}{\text{molecule}} \longrightarrow \underset{\text{solution}}{\text{molecule}} \longrightarrow \underset{\text{solution}}{\text{ions}}$, but $\underset{\text{solid}}{\text{ions}} \longrightarrow \underset{\text{solution}}{\text{ions}} \longrightarrow \underset{\text{solution}}{\text{molecule}}$.

Molecular Complexes.—Molecular complexes are formed by the interaction of the stray fields of simple compounds. Molecular compounds are formed when two molecules hold together. Complex ions result from the entangling of a simple ion by the fields of a "neutral" molecule.

Hydrates are typical *solid molecular compounds.* In order that such a compound shall be formed, it is essential that both

[43] The fact that the carbonate group, being a weak anion, is unable to draw the extra calcium electrons near to it with the production of the large doublets present in sodium nitrate is also of influence in reducing the solubility.

constituents shall be possessed of fairly large outside fields. In compounds where the binding electrons are held between the electropositive and electronegative portions, the fields are more condensed together and more stable than those of the extreme electrolytes. Complexes formed by them are more *stable* than those involving ionizing substances. The conditions for stability of a hydrate can be shown by an example. In a solution of zinc sulfate the zinc ions, and probably to a lesser extent the sulfate ions, will be combined with varying numbers of water molecules, that is, probably some ions will be anhydrous, some will have one water molecule attached, etc. As the concentration of the solution is increased, some of the zinc ions will hold to sulfate ions forming hydrated as well as non-hydrated zinc sulfate molecules. The non-hydrated molecule of zinc sulfate by reason of the large doublet it contains will tend to become hydrated. There will therefore be in the solution molecules of different degrees of hydration which will in turn tend to acquire more water molecules and also to associate together. When concentration has progressed far enough, this associating tendency will outweigh the reverse action. That particular hydrate will continue to grow which offers the greatest condensation of the forces involved. This will be usually the highest hydrate within which the forces are great enough to overcome the disrupting effect of thermal agitation.

Complex ions.—Complex ions result from the interaction between the fields of a neutral molecule and an ion. The ion becomes imbedded within the fields of the neutral part. A molecule, in order to form the neutral part of a complex ion, must have the following requisites:

1. It must have fields strong enough to hold the ion.

2. The attractions within the molecule must be such that it is not dissociated into ions either as a solid or upon solution.

Such molecules are furnished by compounds of a type intermediate between the molecule-forming and the polar classes, where the electron is held so strongly by the electropositive element that it can pass only part of the way over to the negative atom. The complex formed by the addition of potassium cyanide

to silver cyanide is typical. Silver cyanide possesses a structure similar to silver iodide. The cyanide ion is less strongly negative than the iodide ion, the electron is nearer the silver atom and consequently the doublet is of less moment. The fields within the silver cyanide molecule are quite intense. When the solid is placed in a solution of potassium cyanide, the cyanide ions will become by collision imbedded within these drawn-in fields between the silver atom and the cyanide radical. This additional cyanide ion will so increase the resulting doublet fields that the water molecules are able to cause solution by reason of the interaction of their fields with those of the new silver cyanide anion in the solid.

In future papers it is planned to discuss in detail the information which X-ray determinations of the structure of crystals, infra-red spectra measurements, and specific heat measurements offer concerning the nature of the forces between the atoms in solids, and to present the results of X-ray studies of various typical crystals.

SUMMARY

1. The structure of the atom, as we now know it, is discussed with reference to the nature of the forces operating between atoms, and it is emphasized that only the arrangement of the outside electrons has a bearing on the phenomena usually included under the term "chemistry." The arrangement of the inner electrons cannot be deduced from chemical data alone. The outstanding fact is the tendency, still unexplained, to form "closed clusters" of eight or twice-eight electrons.

2. Several typical compounds are considered with reference to the nature of the forces producing them. All compounds lie between the two extremes of "polar" and "non-polar" compounds. A simplified method of representing the type of combination in a given compound is suggested.

3. Solid substances are classified, according to the nature of the forces of combination, into molecule-forming, polar, and valency compounds.

4. The phenomena of adsorption, solubility, ionization in solution, formation of complex ions, and molecular complexes are discussed from this point of view.

ANTHROPOLOGY.—*Some general notes on the Fox Indians.*[1] Part III: *Bibliography.* TRUMAN MICHELSON, Bureau of American Ethnology.

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BOAS, FRANZ. *The Indian languages of Canada.* Annual Archaeological Report 1905: 88–106. Toronto. 1906.
The description of Algonquin (94, 95) is based essentially on Jones' first paper.

FLOM, GEORGE T. *Syllabus of vowel and consonantal sounds, in Meskwaki Indian.* 1906. Published by the State Historical Society of Iowa.
Known to me only by the remarks on p. vi of *A collection of Meskwaki Manuscripts* and in the list of names of Meskwaki Indians in the *Iowa Journal of History and Politics*, April, 1906. The title may therefore not be absolutely accurate. To judge from the orthography of the Indian names, the phonetic scheme is deficient. Apparently the author was unacquainted with the work of William Jones.

JONES, WILLIAM. *Some principles of Algonquian word-formation.* Amer. Anthrop. n. ser. 6: 369–411. 1904.
The first scientific paper on the Fox language.

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Explains the principles of a number of Fox syllabaries. Only the first one described is in current use. At least two others not described by Jones exist; however, their mechanism is on the same lines.

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MICHELSON, TRUMAN. *Some general notes on the Fox Indians.* Part II: *Phonetics, folklore and mythology.* Journ. Wash. Acad. Sci. 9: 521–528. 1919.
See 521–525. There are some unfortunate misprints, which are corrected in an errata sheet preceding the index.

WARD, DUREN J. H. *The Meskwaki people of to-day.* Iowa Journ. Hist. Pol. 4: 190–219. 1906.
Gives the more current syllabary; also the phonetic elements of the Fox language as he conceives it. The priority of this paper or Jones' second one is unknown. The phonetic scheme is better regarding vowels than consonants. It is deficient in important respects. The philosophic tendencies are those of Gobineau, on which see Boas, *Mind of Primitive Man*, Chap. V (1911) and Michelson, Journ. Wash. Acad. Sci. 7: 234. 1917.

[1] Published with the permission of the Secretary of the Smithsonian Institution.

[2] The vocabularies, etc., contained in the works of early writers, such as Marston, Forsyth, Galland, Fulton, and Busby, are passed over, for the words are so badly recorded as to be utterly useless.

WELD, LAENAS G.; RICH, JOSEPH W.; FLOM, GEORGE T. *Prefatory note.* Coll. Meskwaki Manuscripts, Publ. State Hist. Soc. Iowa. 1907: v–vii.
Remarks on the alphabet employed by Cha kā ta ko si (ordinarily known as "Chuck") in volume; various remarks on the phonetic elements of Fox. Not of much value. The fact that j is used for the ch sound does not point to French influence as is stated: j in French has the value of z in azure; while j in the "Manuscripts" certainly for the most part has the phonetic value of dtc. It is more likely that the j is a reflection of English j, heard in a slightly faulty manner. The alphabet is certainly not in common use among the Foxes; and I suspect Chuck invented it. The Indian texts contained in the volume can be used by the specialist.

FOLKLORE AND MYTHOLOGY

BLAIR, EMMA HELEN. *Indian Tribes of the Upper Missisipi Valley and the Great Lakes Region.* 2: 142–145. 1912.
The volume contains Marston's letter to Rev. Dr. Jediah Morse, dated November, 1820; originally printed in the latter's report to the Secretary of War, dated November, 1821, printed at New Haven, 1822. The supposed historic statement that the Shawnees were descended from the Sauk nation by a (Sauk or Fox?) chief, is nothing more than a (Sauk or Fox?) variant of the "Bear-foot Sulkers," on which see Jones, *Fox Texts:* 30, 31. To-day the Shawnee tell it of the Kickapoo and *vice versa* (Michelson, information).

BUSBY, ALLIE B. *Two summers among the Musquakies.* 1886.
Contains extract from Isaac Galland's *Chronicles*, etc. See below.

FULTON, A. R. [Initials stand for?] *The Red Men of Iowa.* 1882.
Contains extract from Isaac Galland's *Chronicles*, etc. See below.

GALLAND, ISAAC. *Chronicles of Northamerican savages.* 1835.
Complete copies are apparently impossible to obtain. Has important information on the gentes and tribal dual division. Part of this cannot be substantiated to-day. Portions reprinted in *Annals of Iowa*, 1869, under the title of *Indian Tribes of the West* (especially 347–366), also in Fulton's *The Red Men of Iowa*, 1882 (131–134), also in Busby's *Two summers among the Musquakies*, 1886 (52–63).

JONES, WILLIAM. *Episodes in the culture-hero myth of the Sauks and Foxes.* Journ. Amer. Folk-Lore 15: 225–239. 1901.

JONES, WILLIAM. *Fox texts.* 1907.
Most important of all publications on the subject.

JONES, WILLIAM. *Notes on the Fox Indians.* Journ. Amer. Folk-Lore 24: 209–237. 1911.
Contains much matter supplementary to his *Fox Texts*.

MARSH, CUTTING. Letter to Rev. David Greene, dated March 25, 1835. Printed in *Wisc. Hist. Coll.* 15: 104–155. 1900.
Traditions regarding the Me-shaum (phonetically mi'cām^{mi}'), We-sah-kah (Wi'sa'kā'^{a}', the culture-hero), the death of his brother, the flood, etc. See pp. 130–134. Most of the information given can be substantiated to-day. The parts of the letter appurtenant to Fox ethnology, folklore and mythology have been reprinted in the appendix to M. R. Harrington's *Sacred bundles of the Sac and Fox Indians* (1914).

MARSTON, MAJOR M. Letter to Rev. Dr. Morse. 1820. Printed in Morse's *Report to the Secretary of War*, 1822.
See p. 122 for a supposed historic statement which is nothing more than legendary: *vide supra* under Blair.

MICHELSON, TRUMAN. *Notes on the folklore and mythology of the Fox Indians.* Amer. Anthrop., n. ser. 15: 699, 700. 1913.
Points out that Fox folklore and mythology consists of native woodland and plains as well as European elements.

MICHELSON, TRUMAN. *Ritualistic origin myths of the Fox Indians.* Journ. Wash. Acad. Sci. 6: 209–211. 1916.

MICHELSON, TRUMAN. *Some general notes on the Fox Indians.* Part II: *Phonetics, folklore and mythology.* Journ. Wash. Acad. Sci. 9: 521–528. 1919.
General discussion of Fox folklore and mythology.

OWEN, MARY ALICIA. *Folklore of the Musquakie Indians of North America.* 1904.
See the review by Michelson in *Curr. Anthrop. Lit.* 2: 233–237. 1913.

STEWARD, JOHN FLETCHER. *Lost Maramech and earliest Chicago.* 1903.
A number of stories are scattered throughout the text. 57–59: Bull Head and Elk; Wa-sa-ri misprint for Wa-sa-si, or a corruption of some sort; phonetically wā'se'si'^{a}'. Michelson has a variant of this in his unpublished collection. 59–62: Wi-sa-ka and the Dancing Ducks; variant to Jones' *Fox Texts*, 278–289; a Sauk version collected by Michelson agrees in part quite closely with tale collected by Steward. 62–65: They who went in pursuit of the Bear; variant to Jones' *Fox Texts*, 70–75. 345–351: Wa-pa-sai-ya; variant to Jones' *Fox Texts*, 8–31, and his *Notes on the Fox Indians*, 231–233; two unpublished versions collected by Michelson agree more closely with those of Jones than with that of Steward.

ETHNOLOGY

ARMSTRONG, PERRY A. *The Sauks and the Black Hawk War.* 1887.
Quite a bit of Sauk ethnology may be gleaned from this. Marred by the statement (13) that with the "Sauks, like all other Indian nations, the gens ran in the female line"—which is an absurdity, and is not only opposed to the information given by the Sauk Indians of today, but is in direct contradiction to the testimony of Morgan (1877) and Forsyth (1827; see Blair, *infra*). Evidently the author was under the influence of Morgan's general theories as was McGee (*Amer. Anthrop.* 1898: 89).

ATWATER, CALEB. *The Indians of the northwest.* 1850.
See especially pp. 72, 76, 81, 87, 93, 104, 105, 106, 107, 115, 123, 129, 130, 132, 175. The time referred to is 1829.

BELTRAMI, GIUCOMO C. *A pilgrimage,* etc. 1828.
See his letter dated May 24, 1823, in vol. 2.

BLAIR, EMMA HELEN. *The Indian tribes of the Upper Mississipi Valley and the Great Lakes Region.* 1912.
Vol. 2 contains Major Marston's letter to Jediah Morse, dated November, 1820; originally printed in the latter's report to the Secretary of War, dated 1821, printed 1822; and Thomas Forsyth's "Account of the Manners and Customs of the Sauk and Fox nations of Indian Traditions," a report to General Clark dated St. Louis, January 15, 1827. These two are the best accounts of Fox ethnology. Forsyth's "Account" is printed here for the first time.

BUSBY, ALLIE B. *Two summers among the Musquakies.* 1886.
Besides containing extract from Galland (see *infra*), also gives lists of gentes, dances, marriage ceremonials, description of some ceremonials, burial customs; clothing, etc. These are the observations of a former school-teacher, and are interspersed with more or less interesting gossip. The ethnological observations for the most part can be substantiated; on some matters (*e. g.*, the "Mule Dance") the author is hopelessly in the dark as to the real import.

CARVER, JONATHAN. *Three years travel,* etc. 1796.
Though published in 1796, refers to thirty years previously, in round numbers. See 30, 31, 145, 170, 219, 230.

CATLIN, GEORGE. *Illustrations of the manners, customs, and condition of the North American Indians.* 1841.
See vol. 2: 207–217. There are other editions. Important. Good for certain dances, clothing, and ethnological facts.

FULTON, A. R. *The Red Men of Iowa.* 1882.
See Chapters VIII and XXIII especially. Contains an extract from Galland, historical and ethnological notes. Needless to say, the translation of Mus-qua-kie "the man with the yellow badge or emblem" and of Sau-kie "the man with the red badge or emblem" should be reversed, and even then the renditions are not accurate; Mus-qua-kie means "Red-Earths;" and Sau-kie is often taken (though mistakenly) to mean "Yellow-Earth." [The last really means "They who came forth." Once given "Red-Earths," "Yellow-Earths" would be a popular etymology, though not correct—witness medial -g-, not -'k-, in the native designation.]

GALLAND, ISAAC. *Chronicles of the Northamerican savages.* 1835.
Contains an account of the gentes, but it is not certain whether the list is for the Sauks or Foxes. The dual division is based on some misunderstanding. Complete copies are apparently not now to be had. Portions reprinted in *Annals of Iowa,* 1869: 194 et seq.; see especially 347–366; also in the popular books of Busby and Fulton.

HARRINGTON, M. R. *Sacred bundles of the Sac and Fox Indians.*
University Museum Anthrop. Publ. 4, no. 2, 1914. See review by Michelson, *Am. Anthrop., n. ser.,* 17: 576-577, by Skinner, *ibidem,* 577–579. Gives a sketch of Sac and Fox culture; detailed description of sacred packs; exquisite photogravures. Besides the references to sacred packs given by Michelson, loc. cit., the following are in order: Armstrong: 37; Beltrami, 2: 159; Keating (see *infra*), 2: 229; *Rep. Comm. Ind. Affairs,* 1851: 66. As long as Skinner gives a reference to a presumably Ottawa pack, attention may be called to *Ann. Prop. Foi,* 4: 481. The Potawatomi term for sacred pack is the phonetic correspondent to the Ottawa pindikossan of Perrot [Michelson], as is evidently the Ojibwa pindjigossan (taken from Baraga); Cree kaskipitâgan (from Lacombe) stands by itself; Sauk, Kickapoo, Shawnee all have phonetic equivalents to Fox mi'cimᵐⁱ' (Michelson, information).

HODGE, FREDERICK WEBB. *Handbook of American Indians.* 1907, 1910. Bur. Amer. Ethnol. Bull. 30.
See articles Fox, Sauk. Full bibliographies at end.

JONES, WILLIAM. *The Algonkin Manitou.* Journ. Amer. Folk-Lore 18: 183–190. 1905.
Best exposition of the fundamentals of Fox religion.

JONES, WILLIAM. *Fox texts.* 1907.
Contains incidental ethnological notes.

JONES, WILLIAM. *Mortuary observances and the adoption rites of the Algonquin Foxes of Iowa.* Congres International des Americanists, XV¹: 263–277. 1907.

JONES, WILLIAM. *Notes on the Fox Indians.* Journ. Amer. Folk-Lore 24: 209, et seq. 1911.
Various ethnological notes interspersed with folk tales. Rules governing membership in tribal dual division wrongly given.

KEATING, WILLIAM H. *Narrative of an expedition to the source of St. Peter's River—* in the year 1823. 1824.
See vol. 1. Though primarily concerned with Sauk ethnology, nevertheless should be consulted.

LAHONTAN, ARMAND L. DE. *New voyages to North America.* 1703.
See 2: 85.

LONG, JOHN. *Voyages and travels of an Indian interpreter and trader.* 1791.
See p. 131.

MCKENNEY and HALL. *History of the Indian tribes of North America.* 1854.
Especially good for Fox costumes; contains other valuable facts.

MARSH, CUTTING. Letter to Rev. David Greene, dated March 25, 1835. Printed in *Wisc. Hist. Coll.* 15: 1900.
Reprinted as far as concerns Fox ethnology, etc., in Harrington's *Sacred bundles.* Information on the whole, good.

MICHELSON, TRUMAN. *Notes on the social organization of the Fox Indians.* Amer. Anthrop. n. ser. 15: 691–693. 1913.
It is possible that the information given may have to be modified in some details, but not the rules given governing membership in the tribal dual division; and the general proposition that the dual division is for ceremonial as well as for athletic purposes stands.

MICHELSON, TRUMAN. *Terms of relationship and social organization.* Proc. Nat. Acad. Sci. 2: 297–300. 1916.
General discussion of terms of relationship; and Algonquian ones in particular. Discussion of the Fox system is incidental.

MORGAN, LEWIS H. *Systems of consanguinity,* etc. 1871.
The "Sauk and Fox" system is from Sauk informants; some schedules are faulty; the Sauk and the Fox systems are identical (Michelson, information).

MORGAN, LEWIS H. *Ancient society.* 1877.
Gives list of gentes, but whether Sauk or Fox is unknown. The two tribes, though legally consolidated, are distinct ethnologically and linguistically.

OWEN, MARY ALICIA. *Folk-lore of the Musquakie Indians of North America.* 1904.
The ethnological data are untrustworthy; see the review by Michelson, *Curr. Anthrop. Lit.* 2:233–237; that of "A. F. C. and I. C. C." in *Journ. Amer. Folk-Lore* 18: 144–146 is a bare enumeration of the contents of the volume without any attempt at criticism.

PATTERSON, J. B. *Autobiography of Black-Hawk.* 1882.
Has data on Sauk ethnology and so is of value.

PIKE, ZEBULON MONTGOMERY. *An expedition,* etc. (ed. Coues). 1895.
See 338, 339.

REPORTS OF THE COMMISSIONER OF INDIAN AFFAIRS.
For facts beyond population and statistics see reps. for 1851: 66; 1896: 162; 1897: 148; 1898: 161, 166, 171; 1901: 240. As a whole reliable.

INSTITUTIONS AT WHICH THERE ARE FOX ETHNOLOGICAL COLLECTIONS

American Museum of Natural History. Collector: WILLIAM JONES.

Cambridge University Museum of Archeology and Ethnology. Collector: MISS OWEN.

Davenport Academy of Sciences. Collector: TRUMAN MICHELSON.

Field Museum of Natural History. Collectors: WILLIAM JONES, TRUMAN MICHELSON, and one or two others.

Museum für Völkerkunde (Berlin). Collector: TRUMAN MICHELSON.
One sacred pack.

Museum of the American Indian. Collectors, M. R. HARRINGTON, TRUMAN MICHELSON.

United States National Museum. Collector: TRUMAN MICHELSON.
Sacred packs only.

ABSTRACTS

Authors of scientific papers are requested to see that abstracts, preferably prepared and signed by themselves, are forwarded promptly to the editors. The abstracts should conform in length and general style to those appearing in this issue.

GEODESY.—*Grid system for progressive maps in the United States.* WILLIAM BOWIE and OSCAR S. ADAMS. U. S. Coast and Geodetic Survey, Special Publ. 59. Pp. 227, figs. 6. 1919.

This publication contains tables, with the description of their use, which make it possible to construct a "grid" on any map in the United States, similar to the grids used on military maps in Europe during the war. The basis for the grid system in the United States is the polyconic projection. The polyconic projection lines cannot be used to advantage in military operations where it is necessary to compute quickly the distance and direction between two points, but by means of a plane coordinate system, the relation between any two or more points can be obtained easily by the solution of right-angled triangles. The values in the tables in this publication are the plane coordinates for the intersections of 5-minute parallels and meridians. The country is divided into seven zones and any coordinate can be used for each of the seven zones by merely shifting the longitude by 8°. It was impracticable to have a single zone for the whole country, because of its wide extension in longitude. The zones in the United States extend in a north and south direction and are 9° in width. Each zone overlaps the contiguous zones by 1°. This makes it possible to avoid a complete break in the plane coordinates at the margins of the zones. The grid lines of two zones can be used on the maps in the overlapping areas and thus provide a connection between them.

The origin for each zone is outside of the United States and is to the southwest of each zone. By having the origin in this location all of the coordinates within the zone are positive. The X-coordinates increase to the eastward and the Y-coordinates to the northward.

A careful study was made of the various projections in general use

before deciding on the one to be used as the basis for the grid tables. The Lambert projection, which was used in France, was not applicable to the United States because of the great range in latitude in this country.

The publication contains examples of the transformation of the geographic to grid coordinates and the reverse. While the tables were computed especially for use in the construction of military maps in the United States, it is possible that the system may sometime be used on maps for civil purposes. W. B.

PHYSICS.—*Specific heat determination at higher temperatures.* WALTER P. WHITE. Amer. Journ. Sci. **47**: 44–59. January, 1919.

This paper deals with the experimental technic of specific heat determination at temperatures up to 1400° by the "method of mixtures," and continues some earlier presentations. Detailed modifications in furnaces and in methods of transferring to the calorimeter are described. The heat losses attending the dropping of hot bodies into water proved to be surprisingly large; their prevention is probably advisable in accurate work, perhaps by the use of aneroid calorimeters. W. P. W.

PHYSICS.—*The determination of the compressibility of solids at high pressures.* L. H. ADAMS, E. D. WILLIAMSON, and JOHN JOHNSTON. Journ. Amer. Chem. Soc. **41**: 12–42. January, 1919.

This paper describes a method by means of which the volume-change under pressure of a solid may be determined with an accuracy of about one part in 10,000 of the original volume of the solid. Results are presented for the metals gold, copper, silver, aluminum, zinc, tin, cadmium, lead, and bismuth; for the alloys brass and tin-bismuth eutectic; and for sodium chloride, calcium carbonate, and silica, both crystalline and amorphous. The pressure range was 2,000 and 12,000 megabars (1 megabar = 0.987 atm.). The $P - \Delta V$ graphs which show the relation between volume-change and pressure were found to be nearly straight lines; however, the more compressible metals exhibit a slight but unmistakable curvature such that the graphs are concave toward the pressure axis. From this curvature a rough estimate was obtained of the change of compressibility between 0 and 10,000 megabars of all the solids examined (except gold, copper, silver, aluminum, and brass, for which the compressibility is independent of pressure within the error of experiment). L. H. A.

INORGANIC CHEMISTRY.—*The thermal dissociation of sulfur dioxide.* J. B. FERGUSON. Journ. Amer. Chem. Soc. 41: 69–72. January, 1919.

The degree of dissociation and the equilibrium constants for the dissociation of sulfur dioxide have been calculated from the equilibrium measurements of the reduction of sulfur dioxide by carbon monoxide and the dissociation of carbon dioxide, and the results of these calculations for a number of temperatures and pressures are given in this paper. The values obtained confirm the experimental results which indicated that the dissociation was too slight to be directly studied by the present available methods. J. B. F.

ANALYTICAL CHEMISTRY.—*A contribution to the methods of glass analysis, with special reference to boric acid and the two oxides of arsenic.* E. T. ALLEN and E. G. ZIES. (Geophysical Lab. Papers on Optical Glass, No. 5.) Journ. Amer. Ceramic Soc. 1: 739–786. Nov., 1918.

Arsenic. An accurate method for the separation and determination of both trivalent and pentavalent arsenic in glasses is described. The separation depends on the volatilization of the trivalent arsenic as AsF_3 when the glass is heated with hydrofluoric and sulfuric acids, while the pentavalent arsenic remains in the residue. The procedures described for arsenic in glasses are generally applicable to substances in which the arsenic can be transformed into sulfide without loss, and are highly accurate. A comparison of the iodometric method and the magnesium pyroarsenate method for arsenic in glasses is made. The former has the advantage in accuracy, and also in speed except where occasional determinations are called for.

Boric Acid. For the determination of boric acid we have found that Chapin's method is very reliable and yields highly accurate results. It has been shown that in order to obtain very accurate results a "blank" must be made and the value applied as a correction to the amount of boric acid found. The correction is small and for ordinary work can be neglected. The accuracy of the method is very appreciably affected by relatively large amounts of *arsenious* acid but not by *arsenic* acid. Relatively large amounts of fluorides appreciably affect the accuracy of the determination but do not seriously impair its usefulness for ordinary work.

Other Determinations. Experience with the following cases in glass

analysis is detailed: (1) The determination of the minute quantities of iron in *optical* glass; (2) the separation and determination of zinc; (3) the separation and determination of lead and barium occurring together; (4) the separation of calcium or barium from relatively large quantities of aluminum occurring with almost no iron; (5) the determination of those elements in boric acid glasses with which the boric acid interferes. Attention is called to the universal presence of hygroscopic moisture in powdered glass samples. Some data by E. S. Shepherd on gases in glass are given. E. T. A.

GEOLOGY.—*Salt resources of the United States.* W. C. PHALEN. U. S. Geol. Survey Bull. **669**. Pp. 284, pls. 17, figs. 16. 1919.

This bulletin describes the geology of the salt deposits of the United States, discussing separately by States the position and extent of deposits, and the stratigraphy and structure of the region, and gives a bibliography for each State. It also gives theories of origin and formation of salt deposits; the chemical composition of saline materials; and statistics of the production of salt in the United States from 1880 to 1917. R. W. STONE.

GEOLOGY.—*Clays and shales of Minnesota.* FRANK F. GROUT. U. S. Geol. Survey Bull. **678**. Pp. 251, pls. 16, figs. 38. 1919.

This bulletin comprises a discussion of the distribution, origin, properties, classification, and adaptability of the clays and shales of Minnesota. An attempt has been made to test all the more important deposits with sufficient exactness to determine for what purposes they may be used. The general character of each geologic formation and the character of the clay products made from it by the several methods of manufacture are set forth. Deposits suitable for common brick are abundant and widely distributed in many accessible localities in the eastern part of the State. The red laminated clay of the eastern counties makes good red brick and may be used as a slip glaze for semi-refractory ware. R. W. STONE.

GEOLOGY.—*The Anvik-Andreafski region, Alaska.* GEORGE L. HARRINGTON. U. S. Geol. Survey Bull. **683**. Pp. 69, pls. 7. 1918.

The Anvik-Andreafski region as described in this report embraces the territory west and north of the lower Yukon River between Anvik and Andreafski rivers and an extensive area of low-lying country immediately contiguous to the Yukon on its east and south sides.

Greenstones of a rather wide range in composition and origin make up a large proportion of the metamorphic rocks. Closely associated with the greenstones are slates, quartzites, and conglomerates and many intermediate rock types. The greenstones appear to have suffered the most intense changes, but secondary structure has developed in the sediments also. Undeformed acidic dikes cut both the greenstones and the sediments. It is tentatively assumed that the greenstones, including the tuffs and some conglomerates which occur with them, are of late Paleozoic age and that the sedimentary rocks are the metamorphosed equivalents of the Cretaceous beds found elsewhere in this region.

Cretaceous rocks were found on Anvik and Andreafski rivers and probably occupy much of the intervening area. More or less closely associated with the Cretaceous rocks in the northern and eastern parts of the region are a series of tuffs and flows of intermediate basic types. Some of the flows appear to be intercalated with the Cretaceous sediments. In the southern part of the region are a number of dacitic porphyry dikes of late Cretaceous or post-Cretaceous age.

No sediments of known Tertiary age were found in the area, but at somewhat widely separated points vesicular lavas occur as undeformed horizontal flows which are either late Tertiary or early Quaternary. Quaternary deposits are found throughout the region.

At the beginning of the Quaternary period the surface stood at a somewhat higher elevation than now, and the base-level of erosion was lower, so that many of the streams were able to carve deeper valleys in bedrock than those they now occupy. It appears likely that the stream systems had become well established and a fairly mature topography had been developed. At some time in this stage of erosion there was an extravasation of basaltic lava which materially altered the courses of some of the larger streams, possibly including the Yukon itself or its predecessor.

The report concludes with a discussion of the mineral resources of the region. R. W. STONE.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

WASHINGTON ACADEMY OF SCIENCES

BOARD OF MANAGERS

At the meeting of the Board of Managers on April 30, 1919, the special committee on distribution of the *Proceedings* reported that 50 reserve sets had been wrapped, and arrangements had been made for the distribution of the greater part of the remaining complete sets.

At the meeting of the Board on May 26, 1919, the following committees were authorized and appointed: Committee to present to the Congressional commission on reclassification of government employees the desirability of enlisting the aid of the National Research Council: P. G. AGNEW and W. J. HUMPHREYS; committee to prepare information concerning scientific and technical positions in the government bureaus, for the assistance of the Reclassification Commission: F. L. RANSOME, F. V. COVILLE, E. B. ROSA, C. S. SCOFIELD, R. B. SOSMAN, W. T. SWINGLE.

At the meeting of the Board on June 30, 1919, the membership of the Academy in the American Metric Association was continued, and problems of reclassification, salaries, and retirement were discussed.

At the meeting of the Board on October 27, 1919, a committee consisting of PAUL BARTSCH, F. V. COVILLE, and F. L. RANSOME was requested to make a report concerning the relation of the Shaw Aquatic Gardens to the proposed engineering improvements along Anacostia River.

The following persons have become members of the ACADEMY since the last report in the JOURNAL:

Mr. OSCAR S. ADAMS, U. S. Coast and Geodetic Survey, Washington, D. C.

Dr. ARTHUR CHADEN BAKER, Bureau of Entomology, U. S. Department of Agriculture, Washington, D. C.

Mr. HERBERT SPENCER BARBER, National Museum, Washington, D. C.

Dr. CHARLES FRANKLIN BROOKS, U. S. Weather Bureau, Washington, D. C.

Mr. ALBERT FRANKLIN BURGESS, Bureau of Entomology, Melrose Highlands, Massachusetts.

Mr. OTIS FISHER BLACK, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Mr. THEODORE CHAPIN, U. S. Geological Survey, Anchorage, Alaska.

Mr. ARTHUR J. ELLIS, U. S. Geological Survey, Washington, D. C.

Mr. HENRY C. FULLER, Institute of Industrial Research, Washington, D. C.

Mr. LOUIS J. GILLESPIE, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Mr. R. B. HARVEY, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Mr. OLIVER BAKER HOPKINS, U. S. Geological Survey, Washington, D. C.

Mr. JAMES A. HYSLOP, Bureau of Entomology, U. S. Department of Agriculture, Washington, D. C.

Mr. JAMES T. JARDINE, U. S. Forest Service, Washington, D. C.

Mr. NEIL M. JUDD, U. S. National Museum, Washington, D. C.

Dr. LYMAN FREDERIC KEBLER, Bureau of Chemistry, U. S. Department of Agriculture, Washington, D. C.

Dr. GEORGE RICHARD LYMAN, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Mr. S. C. MASON, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Dr. EVERETT FRANKLIN PHILLIPS, Bureau of Entomology, U. S. Department of Agriculture, Washington, D. C.

Mr. FRED J. PRITCHARD, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Mr. ARTHUR W. SAMPSON, U. S. Forest Service, Washington, D. C.

Mr. E. RALPH SASSCER, Bureau of Entomology, U. S. Department of Agriculture, Washington, D. C.

Mr. JOSHUA J. SKINNER, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

ROBERT B. SOSMAN, *Corresponding Secretary.*

134TH MEETING

The 134th meeting of the ACADEMY was held jointly with the Chemical Society of Washington in the Assembly Hall of the Cosmos Club, the evening of Thursday, March 27, 1919. Dr. ARTHUR L. DAY, Director of the Geophysical Laboratory, Carnegie Institution of Washington, and Vice-President of the Corning Glass Works, Corning, New York, delivered an address on *Optical glass*. The lecturer outlined the position of the United States with respect to supplies of optical glass both in 1914, when imports from Europe began to be interrupted, and in 1917, when the United States entered the war. The danger from American dependence on European supplies had been recognized before 1917 and some progress had been made in this country in the manufacture of optical glass; but the situation was unsatisfactory, because the prospect that the supply would increase with sufficient rapidity to keep pace with the demands of the American Army seemed remote. Intensive efforts to stimulate the production of the one plant that was then producing glass in appreciable quantity, and the bringing into production of two additional commercial plants in the latter part of 1917, had by November, 1918, solved the problem of an adequate supply. At the same time laboratory and plant research had secured improved raw materials and had gotten at the many diffi-

culties with manufacturing processes, so that the quality also had been brought up to a high standard. The lecturer showed lantern slides illustrating the various processes used in manufacturing optical glass, together with curves indicating the rapid increase in American production in 1917 and 1918.

135TH MEETING

The 135th meeting of the ACADEMY was held in the Assembly Hall of the Cosmos Club, the evening of Friday, April 4, 1919, the occasion being an address by Lieut. Col. BYRON C. GOSS, U. S. A., Chief Gas Officer, Second Army, A. E. F., entitled *Gas warfare at the front.* The lecture was devoted principally to the military features of gas offense and defense, as experienced by the American Army in 1918. At this stage of the war reliance was placed mainly on gas shell, and the gas cloud, which was the method by which gas warfare was introduced in 1915, was very little used. The use of toxic shell may be divided into three periods. From May, 1915 to July, 1916 only lachrymatory shell were used. Phosgene and chlorpicrin shell, intended to produce casualties, came into increased use from July, 1916 to July, 1917. With the latter date began the use of the so-called "mustard gas." The tactical handling of gas shell depends on the object to be accomplished, whether the production of casualties or the neutralization of troops. Details of tactics and of shell design were ably discussed by the lecturer and were illustrated with lantern slides. The lecture closed with the presentation of some new moving pictures showing the use of thermit bombs and smoke clouds and the handling of gas shell by American artillery at the front in the autumn of 1918.

136TH MEETING

The 136th meeting of the ACADEMY was held in the Assembly Hall of the Cosmos Club, the evening of Thursday, May 15, 1919. An address was delivered by Prof. JOHN C. MERRIAM, Acting Chairman of the National Research Council, entitled *Cave hunting in California.* The discovery of prehistoric stone implements supposed to be from the auriferous gravels of California aroused interest some years ago in the question whether man was present on the West Coast during Pliocene or Pleistocene time. The lecturer outlined his early studies of the problem through the examination of auriferous gravels, river terrace gravels, and caves, illustrating the story with many lantern slides of California caves. Among the localities where significant material was obtained were Mercer's Cave in Calaveras County, Hawver's Cave and the Robbers' Cave in the American River valley, and Potter Creek Cave and Sarnwel Cave on the McCloud River. Many new species of extinct Pleistocene animals were found in the course of the explorations, but no absolutely certain evidence has been discovered of the existence of man in California before the present epoch. The lecture was discussed by several members of the Academy.

WILLIAM R. MAXON, *Recording Secretary.*

SCIENTIFIC NOTES AND NEWS

ANNOUNCEMENTS OF MEETINGS OF NATIONAL SCIENTIFIC AND ENGINEERING SOCIETIES

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. St. Louis, Missouri, December 29–31, 1919. Chicago, Illinois, December, 1920.

NATIONAL ACADEMY OF SCIENCES. Washington, D. C., April, 1920.

AMERICAN CERAMIC SOCIETY. Hotel Walton, Philadelphia, Pennsylvania, February 23–26, 1920.

AMERICAN CHEMICAL SOCIETY. St. Louis, Missouri, April 13–16, 1920. Chicago, Illinois, September, 1920.

AMERICAN PHYSICAL SOCIETY. Chicago, Illinois, November 28–29, 1919.

GEOLOGICAL SOCIETY OF AMERICA. Boston, Massachusetts, December 29–31, 1919.

AMERICAN SOCIETY OF ZOOLOGISTS. St. Louis, Missouri, December 29–31, 1919.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. New York City, February 18–20, 1920. Annual Convention, June 22–25, 1920; place not yet decided upon.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS. New York City, December 2–5, 1919. St. Louis, Missouri, probably May, 1920.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. New York City, February 16–20, 1920.

NATIONAL ELECTRIC LIGHT ASSOCIATION. Pasadena, California, May 18, 1920.

THE MAP-MAKING CONFERENCE

On July 1, 1919, the Engineering Council addressed a letter to the President of the United States suggesting that a conference of the map-making bureaus of the Federal government be called in order to make plans for cooperation and for expediting the completion of the topographic map of the United States. On August 27 the President referred the matter to the Secretary of War and requested that a conference be called.

The conference was held on September 15–29, and the following fourteen map-making organizations of the Federal government were represented: U. S. Coast and Geodetic Survey, U. S. Geological Survey, General Land Office, Topographic Branch of the Post-Office Department, Bureau of Soils, U. S. Reclamation Service, Bureau of Public Roads, Bureau of Indian Affairs, International (Canadian) Boundary Commission, Forest Service, U. S. Hydrographic Office, and the following organizations from the U. S. Army: Corps of Engineers, Mississippi River Commission, and U. S. Lake Survey. Ten national scientific and engineering societies were also represented.

The conference reached the general conclusion "that there is little actual duplication of effort materially affecting the progress of mapping the United States. The U. S. Geological Survey is charged with the preparation of a topographic map of the United States, which, with certain minor modifications, will adequately meet the needs for a general utility map. The work of that bureau is progressing as rapidly as the available funds will permit. Approximately one-third of the area of the continental United States, exclusive of Alaska, is now covered by satisfactory maps of this class. The U. S. Coast and Geodetic Survey, in addition to its other work, is engaged in the execution of the primary control in the interior of our country. A basic horizontal and vertical control which will permanently establish some geographic position and elevation within about 50 miles of any point in the United States has been approximately 50 per cent completed. Close cooperation exists between the U. S. Coast and Geodetic Survey and the U. S. Geological Survey so that there is no duplication in carrying out the work necessary for the standard topographic map."

The report also shows that certain map needs of various other bureaus are met by the standard topographic map of the Geological Survey. In addition, they all require certain special maps, some of which demand more detailed surveys than those necessary for the standard map, and others of which require the collection of entirely different kinds of data. Some of the organizations concerned (for instance, the International Boundary Commission) are conducting specialized surveys, and while they would be benefited in some degree by the early completion of the standard map in the areas in which they operate, still this map would not obviate the need of the special surveys. The work of the Hydrographic Office is entirely outside the continental limits of the United States.

The conference adopted the following recommendation: "It is recommended that the present procedure be continued, under which the U. S. Coast and Geodetic Survey executes the primary control of the area of the United States and U. S. Geological Survey prepares, publishes, and distributes the standard topographic map and that Congress be asked to make larger appropriations for these purposes in order that the complete map may be available at an early date. * * * * * It is further recommended that this general project be approved and placed before Congress with the request that Congress adopt the project for execution by successive annual appropriations for these two bureaus. Under this general plan it is assumed that a large number of States will continue to cooperate in topographic mapping by making specific appropriations for that work."

The conference also recommended: (1) that a permanent Board of Surveys and Maps be appointed to act as an advisory body; (2) that a central information office be established, preferably in the U. S. Geological Survey, but under the general supervision of the Board of Surveys and Maps; (3) that the copyright laws be so amended as to provide that a copy of every map presented for copyright be trans-

mitted to the information office; (4) that all Government agencies be instructed to comply with requests for data from the Board; (5) that surveys by agencies other than the Geological Survey be made to conform to the specifications of the standard topographic map; (6) that the Coast and Geodetic Survey be given general supervision of the final adjustment of all important control data; (7) that maps be issued as soon as possible after the field work has been completed; and (8) that the program of the Interdepartmental Committee on Aerial Surveying be approved.

It is estimated that the work of primary control can be completed by 1933 at a cost of $6,305,000, and that the topographic map can be completed within the same period for $40,490,000 (including cooperative appropriations by States).

NOTES

Mr. C. H. BIRDSEYE has been appointed Chief Topographic Engineer of the U. S. Geological Survey, to succeed Mr. R. B. MARSHALL, who recently resigned as Chief Geographer. Mr. Birdseye was formerly chief of one of the divisions of topographic mapping and during the War served in France as Lieutenant Colonel of the Coast Artillery. Mr. Marshall will remain a member of the Survey, being enrolled as a topographic engineer on a per diem status, and will thus be available for occasional service.

Prof. M. A. CARLETON has resigned his position as cerealist with the U. S. Department of Agriculture, and is now engaged in special field investigations for the U. S. Grain Corporation, with headquarters at 42 Broadway, New York City.

Dr. HENRY A. CHRISTIAN, Dean of the Harvard Medical School, came to Washington on November 1 as chairman of the Division of Medical Sciences of the National Research Council.

Mr. D. DALE CONDIT has resigned from the Geological Survey, and Mr. RALPH W. HOWELL is on a year's leave of absence, to accept positions as petroleum geologists with Pearson and Sons. They sailed for England about the middle of October.

Mr. R. W. FREY, formerly with the leather and paper laboratory of the Bureau of Chemistry, U. S. Department of Agriculture, has resigned to accept a position in the chemical department of John H. Heald & Co., Inc., manufacturers of tanning and dye-wood extracts at Lynchburg, Va.

Dr. ALBERT MANN has resigned from the Department of Agriculture to accept an appointment as Research Associate of the Carnegie Institution of Washington. The change was made so as to enable him to give his entire time to his work on the diatoms. He will have his office and laboratory at the National Museum.

Prof. A. A. MICHELSON, of the University of Chicago, who was until recently engaged in research for the Navy Department at the Bureau of Standards, has been appointed Research Associate at the Mount Wilson Observatory of the Carnegie Institution of Washington, for the year ending July, 1920.

Mr. BERT RUSSELL, first assistant examiner in the Patent Office, and secretary of the Patent Office Society, has resigned in order to devote his attention to chemico-legal work with the firm of Prindle, Wright & Small, of New York City.

Mr. C. E. SIEBENTHAL, geologist of the U. S. Geological Survey, will spend a large part of his time this winter in the Internal Revenue division of the Treasury Department assisting in the adjustment of the income-tax valuation of mining properties.

Prof. C. A. SKINNER, formerly head of the Physics Department at the University of Nebraska, has recently come to Washington as chief of the Division of Optics of the Bureau of Standards.

Dr. M. W. TRAVERS, formerly of the Indian Institute of Science, Bangalore, India, and connected during the war with the manufacture of chemical glass in England, visited Washington in October.

Dr. L. B. TUCKERMAN, formerly professor of Theoretical Physics at the University of Nebraska, has recently joined the Engineering Materials Division of the Bureau of Standards.

Dr. P. V. WELLS, of the Bureau of Standards, is on leave of absence and is spending a year in the laboratory of Prof. PERRIN in Paris.